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THE ENGINEERING FEATURES OF TVA

by Clarence E. Blee

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THE ENGINEERING FEATURES OF TVA

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The watershed of the Tennessee River has an area of 41,000 square miles--about twelve times the area of Puerto Rico. The headwaters of the river are in the Blue Ridge and Smoky Mountain ranges which rise to an elevation of over 6,500 feet. It will be noted from the map, figure 1, that the upper tributary rivers come into the main stem somewhat like the fingers of a hand. Starting in the northwest and following a clockwise direction, the first tributary is the Clinch River on which Norris Dam is located; next is the Holston River with Cherokee Dam on the lower river and Watauga and South Holston Dams on the upper river where two more dams--Boone and Fort Patrick Henry--are now under construction: then the French Broad with Douglas Dam; the Little Tennessee with Fontana Dam and the Aluminum Company dams; and finally the Hiwassee--Ocoee river system with the Hiwassee and Ocoee group of dams. The main river, starting at Knoxville, Tennessee, follows a crescent-shaped course flowing southwest down into Alabama, then west and finally due north into the Ohio River a short distance above its junction with the Mississippi.

Figure 2 is a profile of the Tennessee River System. The main river is completely developed into a series of steps and pools by the nine dams now in operation, each of which includes a navigation lock and a power generating station.

A brief review of the formation of the TVA may be of interest. The Act creating the Tennessee Valley Authority was passed by Congress in May, 1933. The resulting organization was a corporation, in the words of President Roosevelt, "clothed with the power of government but possessed of the flexibility and initiative of a private enterprise." In legal phraseology it could "sue and be sued."

To quote from the opening paragraph of the Act . . . . "to improve navigation in the Tennessee River and to control the destructive flood waters in the Tennessee and Mississippi River Basins, there is hereby created a body corporate by the name of the 'Tennessee Valley Authority.' " Later, in an amendment it was stated, "The Board is hereby directed in the operation of any dam or reservoir . . . . to regulate the stream flow primarily for the purpose of promoting navigation and controlling floods. So far as may be consistent with such purposes, the Board is authorized to provide and operate facilities for the generation of electric energy at any such dam."

Thus, the Act defined the objectives of navigation, flood control and power production.

As now constructed, the system of dams and reservoirs designed to develop and control the waters of the Tennessee River consists of 23 dams constructed or acquired by TVA. Under an agreement with the Aluminum Company of America, TVA also directs the operation and dispatching of that company's five plants on the Little Tennessee River so that the 28 installations operate as one water control system, making the Tennessee River and its tributaries one of the most highly developed river systems in the world. The

combined gross storage capacity of the reservoirs is 22 million acre-feet. The continuous slack-water navigation channel extending from Paducah, Kentucky, to Knoxville, Tennessee has a sailing line length of 630 miles. Eleven and a half million acre-feet of storage space in the reservoirs is reserved for flood control as of January 1, the start of the flood season each year. The power system as of June 30, 1952, has an installed capacity of 2,968,000-kw in hydro-electric generating capacity and 892,000-kw in steam-electric capacity, making a total installed capacity of 3,860,000-kw. Power is supplied wholesale to municipalities and co-operatives within the Tennessee Valley and adjacent areas and directly to a few large industrial consumers and to government agencies. A network of high voltage transmission lines comprising over 8,000 circuit-miles connects the generating stations to the delivery points and to points of interconnection with the neighboring utilities.

The water control system on the Tennessee River is founded largely on the use of multiple-purpose reservoirs. The Tennessee Valley Authority has been something of a pioneer in this respect but today a great many of the dams built by the governmental agencies throughout the world are multiple-purpose structures.

The most important factor in the successful operation of a multiple-purpose water-control system is that the system shall have been planned and designed for the method of operation proposed and then that the design stipulations be strictly adhered to in operation. There are three different methods of approach or concepts as to the design of reservoir projects involving flood control: (1) the idea that a reservoir must at all times be kept empty for flood control, which makes it essentially a single-purpose flood control project: (2) the view that in the multiple-purpose reservoir there must be a designated portion or definite layer of the reservoir reserved for flood control, with no common use of this space; (3) the concept that the same space in a reservoir may be used both for flood control and for other purposes at different seasons of the year.

Each of these concepts has its proper place and each has been successfully and economically employed. The first is essentially the detention type of development--where the dam has a low level, permanently open, fixed outlet. The second method--that of reserving a definite layer of the reservoir for flood control--has been used extensively in the multiple-purpose projects constructed by the Corps of Engineers in the United States. In the development of the extensive water-control system on the Tennessee River it generally has been possible to employ the third method whereby the same space in a reservoir is used for flood control during the flood season and for other purposes during the remainder of the year. The following conditions favorable to such a method of operation are present to a high degree in the Tennessee Valley.

1. Major floods are consistently confined to a definite flood season.
2. The annual runoff cycle is such as to favor the required degree of filling of the reservoirs after the end of the flood season.

While this method has been employed extensively on the Tennessee River System, there has been no dogmatic adherence to this. In planning flood control facilities for the Upper French Broad River in the Tennessee Valley, our engineers have proposed reservoirs of the detention type. Here, conditions are not favorable for power development and major floods may be expected in any season of the year as it is in the area subject to hurricane storms. The design of the Watauga and South Holston projects in the mountainous

section at the northeast end of the Valley is based on reserving throughout the year, exclusively for flood control, the space above a certain fixed elevation in each reservoir. In the case of these projects the topography and lack of development in the area are such that reservoirs of comparatively large storage capacity may be obtained at reasonable cost, making conditions favorable for hydro-electric installation, but in this mountainous section damaging floods may occur in any season of the year.

The important thing is that in planning a multiple-purpose project, all available basic data should be assembled and the proposed method of operation determined by an engineering analysis directed toward serving the objectives in the most economical manner. This problem is like other engineering problems where we have certain controlling data and certain purposes which must be appraised and balanced one against the other, so that the solution arrived at will best fit all the factors involved.

In planning the Tennessee River System, such a procedure has been followed--treating the river as an integrated whole rather than as individual projects. The controlling conditions of rainfall, runoff and flood pattern have been studied and methods of multiple-purpose reservoir operation adopted that most economically produce reliable flood control, adequate navigation facilities, and the greatest amount of power consistent with the major objectives of navigation and flood control.

Systematic stream-flow records for the Tennessee River are available, covering the past 75 years and historical records extend our knowledge to cover a period of well over a hundred years. These records demonstrate that major floods on the Tennessee River are confined to the period between the latter part of December and the first of April. This is the season when valley-wide storms come in from the Gulf of Mexico. Intense precipitation may be caused in the summer months by West Indian hurricanes striking along the eastern end of the basin or by local thunderstorms but neither of these involves sufficient areas to produce a major flood on the main river.

Figure 3 is a chart showing graphically the flood record on the Tennessee River. The upper portion gives the flood stages chronologically as they occurred. In the lower portion they are grouped according to the season of the year and the day of the month. It is evident that no serious floods have occurred between the first part of April and the latter part of December.

Figure 4 shows several interesting conditions. First, that the precipitation is remarkably well distributed throughout the year. It is apparent that irrigation is not a factor in the Tennessee Valley--September, October and November are the only months below the average in rainfall. Another point is the large variation in run-off. The month of July has more rainfall than March but the run-off for July is but little more than 1/3 of that for March.

Water control operations on the TVA system are centralized in the Office of the Chief Engineer under the Chief Water Control Planning Engineer. This administrative procedure has the advantage of establishing a unified control of water operations for all purposes and of placing that control in a division which is familiar with the planned methods of operation for the system.

Unified control is a prime necessity in operating a water control system such as that of the Tennessee Valley Authority with its various functions and interests.

Malaria control is not one of the objectives specifically named in the TVA Act but it has become an important function involving water control operations. The building of an extensive system of reservoirs in a region to which malaria was endemic, necessarily introduces the obligation of controlling the malaria-bearing mosquito in and along the shores of the lakes. One of the most

effective means of accomplishing this is by cyclical fluctuations of the reservoir levels so malaria control becomes a water control operation.

Supplemental means of mosquito control are also employed, including dusting with D.D.T. from airplanes. A determined effort is being made to "build out" mosquito breeding areas and so reduce the cost of repetitive measures. In certain localities it has proven economical to dike and dewater large shallow areas. Again, and this is being practiced quite extensively, flat irregular shore-line areas have been treated by cut-and-fill excavation to produce a straight, steeply sloping shore line. The net result has been to almost eradicate malaria in the Tennessee Valley region. In 1934 surveys indicated that about 28% of the people living in the lower Valley were subject to malaria. Surveys in 1949 for the first time showed no positive evidence of malaria infection.

The forecasting of streamflow is an important part of the mechanics of water control operations. On the TVA system this has been developed into a highly specialized function which is giving excellent results. As extensive network of precipitation and stream-gauging stations is maintained. About 150 key stations on this network normally report each morning to the central forecasting office in Knoxville, Tennessee. During flood periods 90 additional stations send in reports and all reports are received at more frequent intervals. These reports come in by telephone and telegraph and even by radio as a considerable number of automatic radio gauges are used. These automatic radio gauges, initially developed by TVA and now in general use throughout the country, have proved very reliable in operation and have been invaluable in furnishing information from the mountainous regions of the watershed.

In connection with stream-flow forecasting, quantitative weather forecasts furnished by the U. S. Weather Bureau under a cooperative agreement are being used. Forecasts are received twice a day giving the predicted weather conditions and the amounts of rainfall expected in the various sub-divisions of the Valley for three days in advance.

All rainfall and stream-gauge data are assembled by sub-watersheds within the Valley and assigned to specific engineering personnel. Such an engineer becomes familiar with the special characteristics of his particular drainage area and develops remarkable proficiency in computing the stream flows and water level stages involved. The computations from the various sub-divisions are assembled and the stream flows and water level stages throughout the system are computed for three days in advance, based upon the rainfall up to the time of the report. Then, these data are considered in connection with the quantitative weather forecasts and decisions made as to the handling of the water through the system.

In selecting the proper factor to convert rainfall into runoff, good judgment gained by experience and based on extensive data is required. Taking the watershed as a whole, the mean annual rainfall is 52 inches and the corresponding runoff is 23 inches, giving a ratio of runoff to rainfall of 44 percent. This ratio varies considerably in different sections of the Valley and there is a striking seasonal variation as was noted in figure 4. The runoff from individual storms is affected by many factors such as conditions of the soil surface, depth to ground water, rate and duration of precipitation, soil cover, and state of growth of vegetation. The surface runoff from a prolonged storm in the wet season may be as much as 90 percent of the rainfall, while the corresponding runoff from a summer storm with equal intensity of rainfall may be less than 25 percent. This is one reason why major floods do not occur in the summer and fall seasons.

As an aid in long-range scheduling of reservoir operations, methods have been developed estimating the amount of available ground water in storage so that this may be depended upon with something like the reliance that is placed upon water stored in surface reservoirs. The soil of the Valley is in general fine grained and not particularly favorable for the storage and giving up of ground water. Moreover, there is a wide variation in the ground water characteristics of the different basins in the Valley. The 2,912 square-mile area tributary to Norris Reservoir has been found to contribute a maximum of 2.7 inches of ground water, amounting to 420,000 acre-feet, while the corresponding figure for Fontana Reservoir with its deeper soil cover is 8 inches, yielding 670,000 acre-feet from 1,571 square miles.

The job of directing the control of a river system such as the TVA system on the Tennessee River is not a simple one. There are the various program objectives to be considered and the river itself is a complicated feature with its many tributaries and variable pattern of rainfall and runoff. The job can only be done by a unified control, centered in one office.

It is essential that the water control operations follow out the planning and design on which the system was based. To this end, a "Rule Curve" is established for each reservoir which fixes the levels above which the reservoir must not be filled during the flood season except to retain and control a flood. Any departure from the rule curve would stand out like a sore thumb. The records will show that the limitations established by the rule curves have been fully observed in reserving space for flood control. For instance, in January 1947, there was a heavy flood. In helping to control this flood, Douglas Reservoir was filled about 30 feet above the rule curve. As soon as the flood had passed, this water--amounting to about 400,000 acre-feet--was spilled to bring the reservoir level back down to the rule curve and thus be ready to control another flood, if one should occur. As it turned out, from the middle of January on, 1947 was a dry year with rainfall and runoff decidedly deficient, and Douglas Reservoir did not fill. If the operation had been primarily for power, that water spilled in January would have been held over until later in the year and used to produce power.

Engineering Structures

In carrying out this combined program of navigation, flood control and power development over the past 19 years, the TVA forces have constructed or have under construction some 20 dams, 18 hydro-electric power plants, 7 navigation locks, and 6 large steam-electric plants. Other such facilities have been acquired by purchase and transfer.

The seven dams constructed by TVA on the main river are all quite similar in arrangement. Each dam includes a spillway section across the original river channel, consisting of concrete piers and crest gates; at one end of the spillway section is the navigation lock and at the other is the power plant; extending across the flood plain at one or both ends of the main structure is generally a section of rolled earth embankment. The maximum heads for which these dams are designed range from 45 feet at Guntersville to 80 feet at Fort Loudoun Dam. Figure 5 is an airview of Guntersville, a typical main river dam.

The dams on the tributaries naturally vary considerably as to height, general arrangement and materials of construction. In general they are comparatively high structures impounding large storage reservoirs. As to type of construction, the straight gravity concrete dam predominates, but rolled earth-fill and rock-fill dams with rolled earth cores have also been used extensively. The Fontana Dam, with a height of 480 feet, is the highest dam on

the TVA system and, in fact, is the highest dam east of the Rocky Mountains. Figure 6 is a view of the Hiwassee project, a typical tributary dam.

The characteristics of a particular site--the nature of the foundations and abutments, the configuration of the site, and the availability of materials for construction--have much to do in determining the type of dam which is to be constructed. But perhaps changing economic conditions have an even more far-reaching influence. When Norris Dam was constructed (1934-1937) mass concrete was placed for $5.30 per cubic yard including cement, aggregates, etc. In that same period, rolled earth-fill for dam construction cost in the neighborhood of $0.40 per cubic yard in place. Today, the comparable cost of concrete is close to $12.00 per cubic yard (2.3 times the former cost) and the rolled earth fill can be placed for about $0.70 per cubic yard (1.75 times the former cost). The increased size of earth moving equipment and the improvements in this equipment, together with the small amount of labor required, have made dams of fill construction relatively more economical than they were in the early '30's and hence more extensively used.

A problem which has been uppermost in the design and building of a great many of the dams in the Tennessee Valley is that arising from the difficulties inherent in founding a dam on a limestone formation. All of the dams on the main river, with one exception, and many of the dams on the tributaries are located in a limestone formation. The limestone being soluble has, over the geologic ages, developed solution channels and cavaties to varying degrees. Through close cooperation between its design, field engineering and construction forces, the TVA has been able to progressively develop methods and techniques for dealing with these problems. The large diameter calyx drill has been used extensively not only as a means of exploration, but also as a construction devise to give access to deep-lying seams so that the disintegrated rock could be mined out and back-filled with concrete; also in particularly bad rock, intersecting calyx drill holes have been back-filled with concrete to form a continuous cut-off curtain. The improvement in techniques and the experience gained make it possible today to successfully construct major structures on foundations which twenty-five years ago would have been considered impossible.

In the relatively short history of the Tennessee Valley Authority, there have been two periods wherein the demands for power in connection with the national defense effort have called for particularly intense activity on the part of the design and construction divisions. The first period included those years just prior to World War II and running through to the end of the War. The accelerated schedules to produce power for war production called for 12 major projects to be under way at one time, and for one of these projects, Douglas Dam, to be in operation 13 months after starting work.

The era starting early in 1950 and extending to the present and apparently continuing into the near future, constitutes the second of these periods of intense activity. In terms of demand for power, the number of kilowatts added to the installed capacity of the system, and to the dollar expenditures made, this second period has exceeded the first. On the TVA system, in order to keep pace with this heavy demand for power, it has been necessary to turn to the construction of large steam-electric generating plants. Five such plants are now under construction with a total installed capability of 5,200,000 kilowatts. While the present expansion program is predominately steam, the hydro has not been neglected as there are now being installed on the TVA system additional hydro-electric units having a total capability of nearly 400,000 kilowatts.

The Tennessee Valley Authority has afforded a remarkable opportunity for

the engineers associated with it to plan, design, and construct this system of dams, reservoirs, navigation channels, and power facilities--to see these grow into the great project that it is today and to have a part in directing its operation. Too often engineers plan and design without seeing the actual construction and completion of the structures which they have conceived. Here in the Tennessee Valley the work has been concentrated enough in both time and space that the engineers engaged upon it have been able to follow through to the completion of construction and into the operation of the structures in which they have had a part.

THE TENNESSEE RIVER SYSTEM

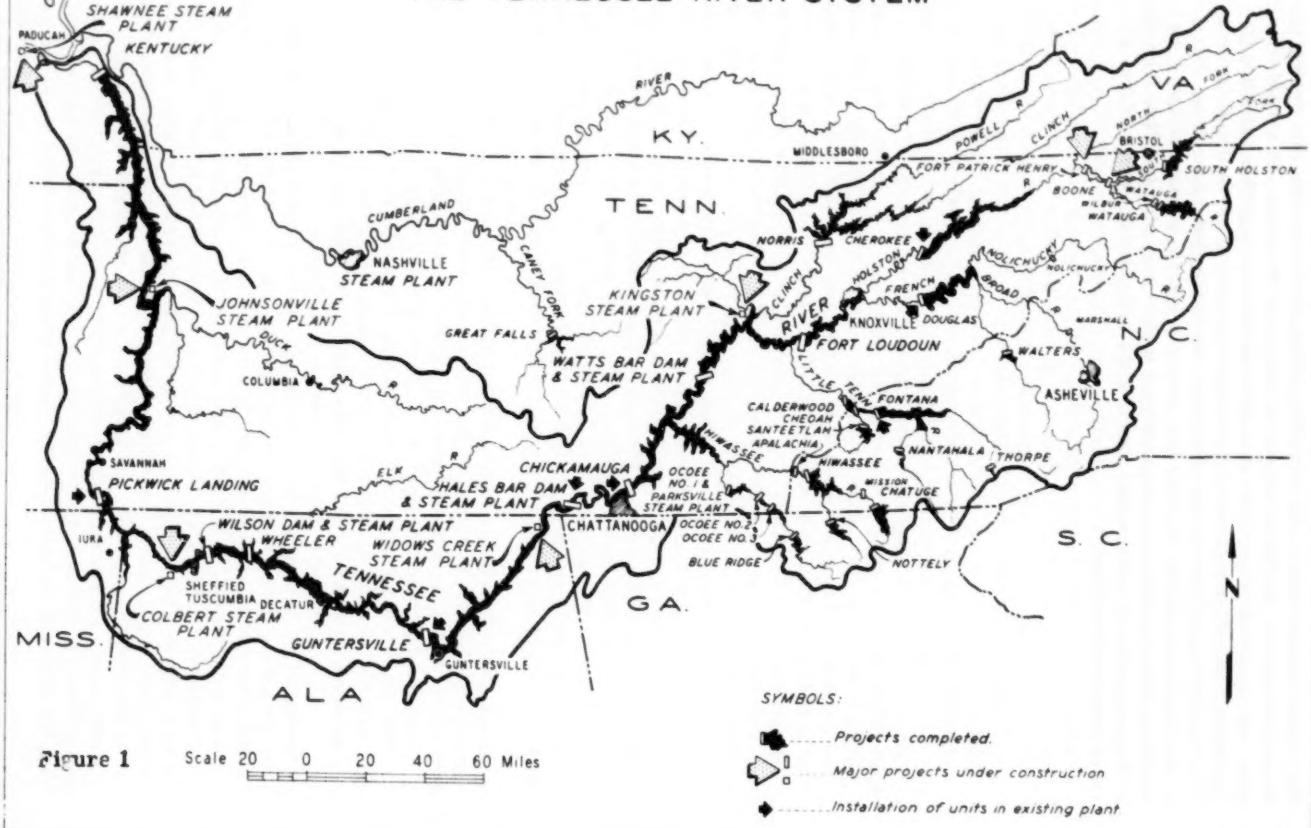
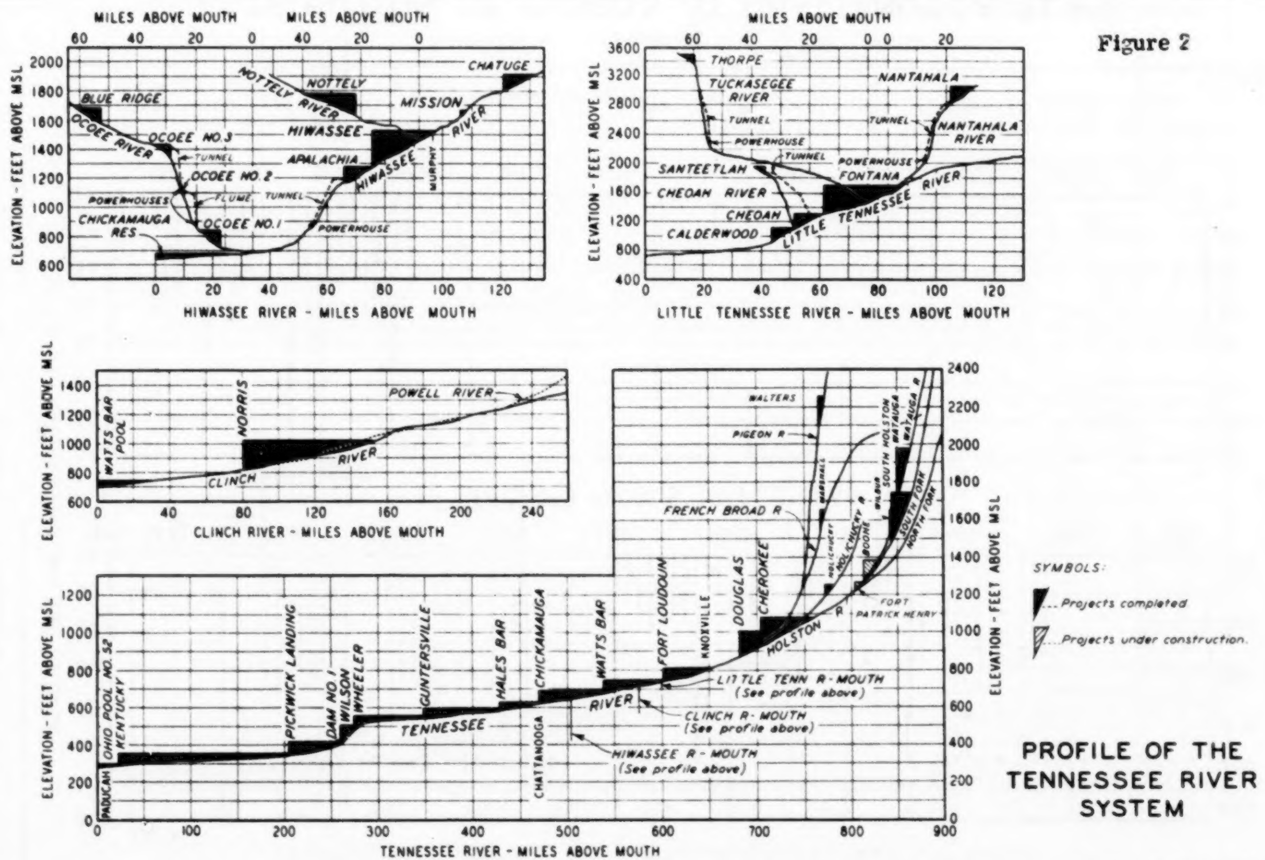


Figure 1

Figure 2



PROFILE OF THE TENNESSEE RIVER SYSTEM

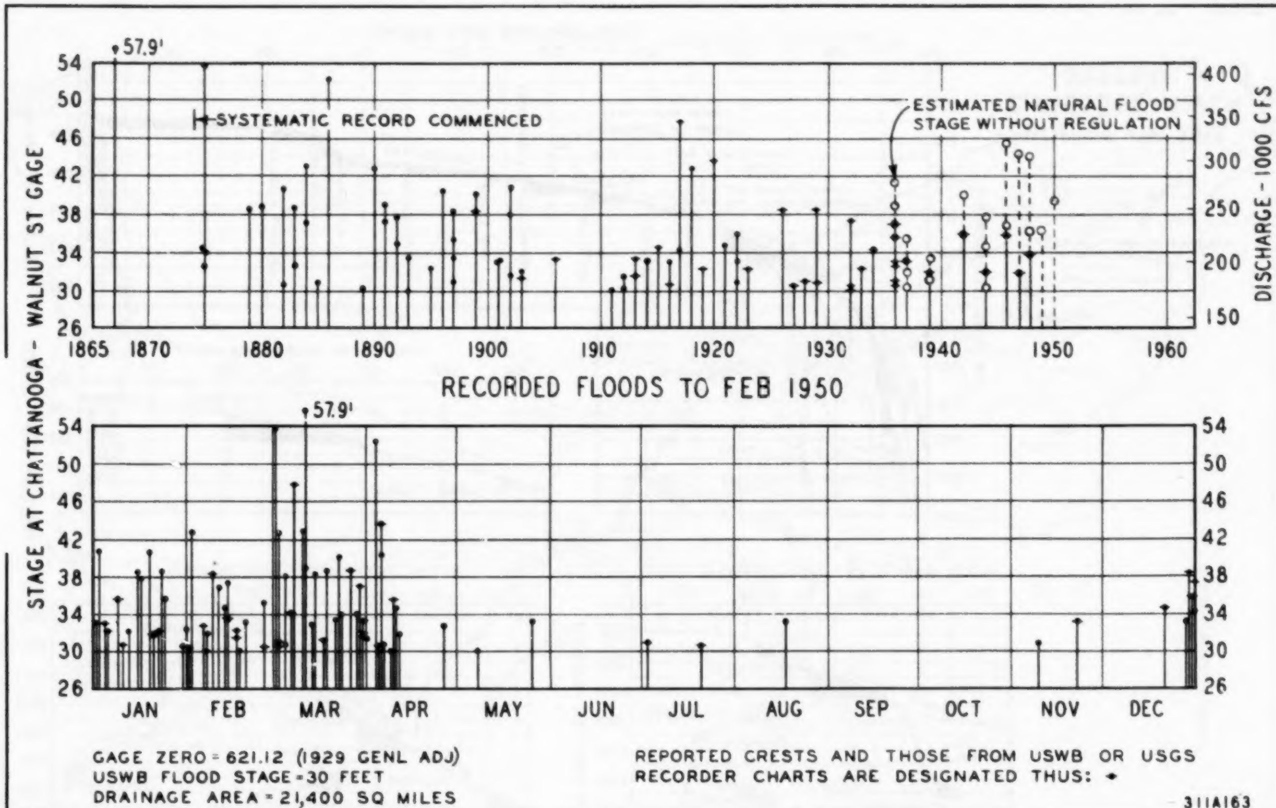
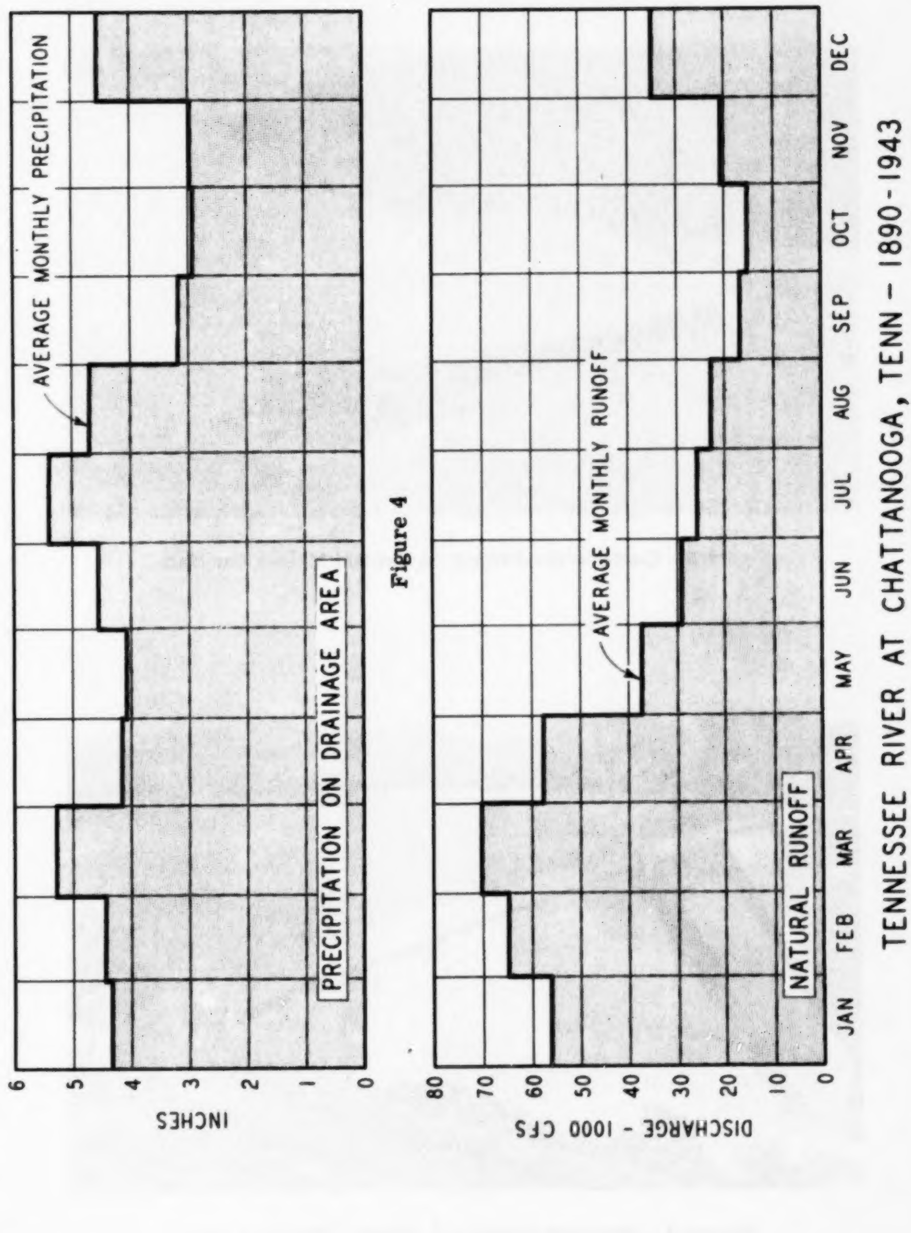


Figure 3

DISTRIBUTION OF FLOODS AT CHATTANOOGA, TENN.


PRECIPITATION ON DRAINAGE AREA
AVERAGE MONTHLY PRECIPITATION
INCHES
0
1
2
3
4
5
6
NATURAL RUNOFF
AVERAGE MONTHLY RUNOFF
DISCHARGE - 1000 CFS
0
10
20
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40
50
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70
80
JAN
FEB
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TENNESSEE RIVER AT CHATTANOOGA, TENN - 1890-1943

Figure 4

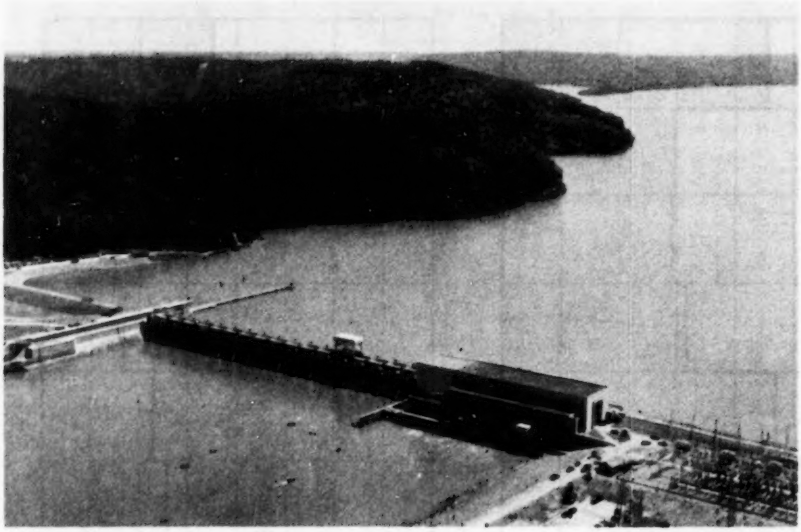

Figure 5 - Guntersville Project, A Typical Main-river Dam

Figure 6 - Hiwassee Project, A Typical Tributary Dam

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